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An association between Waitaki River winter headwater flows and the Interdecadal Pacific Oscillation (IPO)

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Abstract

Expressed as 11-year running means (1945-2008), winter headwater flows in the Waitaki River (New Zealand) and the IPO index show similar patterns in the way they vary over time. However, this effect is not evident in the other seasons. A possible explanation is the IPO in its positive phase is associated with warmer air temperatures in winter, but not in other seasons. Analysis of Mt Cook (Hermitage station) daily rainfalls suggests that warmer winter air temperatures on precipitation days are associated with higher mean daily precipitation, so the positive IPO may result in greater amounts of winter precipitation falling as rain rather than snow. This could provide the link between the winter IPO and headwater discharge. On the other hand, temperature is only weakly associated with precipitation magnitudes in other seasons, when higher average temperatures do not provide the same restricting effect on precipitation as in winter.

Keywords

Interdecadal Pacific Oscillation, Waitaki catchment

Introduction

Variations and trends in New Zealand temperatures and rainfall have been related to circulation changes in the southwest Pacific, with significant shifts in 1950 and 1975 (Salinger and Mullan, 1999). Salinger *et al.* (2001) showed that climatic shifts over the southwest Pacific region within the periods 1922-1944, 1946-1977 and 1978-1998 are linked to the different phases of the Interdecadal Pacific Oscillation (IPO). Particularly, they suggested that the IPO in the positive phase enhances teleconnections between the El Niño Southern Oscillation (ENSO) and climate variability over New Zealand. Similarly, Ummenhofer *et al.* (2009) attributed changes in New Zealand summer precipitation during the period 1976-2006 to changes in both ENSO and the Southern Annular Mode (SAM).

We focus here on the specific instance of an apparent connection between the IPO and winter discharge in the Waitaki headwaters, defined here as the combined inflow volumes into the hydro storage lakes Tekapo and Pukaki. The question considered is: why there should be inflow correlation with the IPO in winter but not in the other seasons? Previous work has not had emphasis on seasonal differences, but an IPO influence on flows in headwater rivers in the Southern Alps has been reported; as the change to a positive IPO phase occurred around 1978, most Southern Alps headwater rivers shifted toward higher discharge magnitudes for both floods and low flows (McKerchar and Henderson, 2003).

Data

The IPO index used here is related to the Pacific Decadal Oscillation (PDO) index. The PDO has been defined as the leading principal component of North Pacific monthly sea surface temperature variability (Mantua *et al.*, 1997). During the positive phase of the PDO the sea surface temperatures (SST) anomalies over the North Pacific are negative while the SST anomalies over tropical Pacific are positive, and vice versa. The IPO index describes the similar quasi-symmetrical oscillation over the whole Pacific basin and was shown to be essentially equivalent to the PDO in the North Pacific (Folland *et al.*, 2002).

In the present study, the Waitaki lakes (Tekapo and Pukaki) inflow records were used subsequent to 1940 because earlier records contain large amounts of missing data (Purdie, 2010). Daily temperature and precipitation data were sourced from the Hermitage station at Mount Cook, taken as indicative of the headwater region. Daily temperature mid-ranges were used (mean of the daily maximum and minimum temperatures) and 'rain-day' refers to mean precipitation (rain or snow) exceeding 0 mm for the day. This will include days of trace precipitation but such days make up less than 10% of rain-day records. The seasonal lake inflow volumes were provided by Meridian Energy Ltd and were derived from lake level differencing.

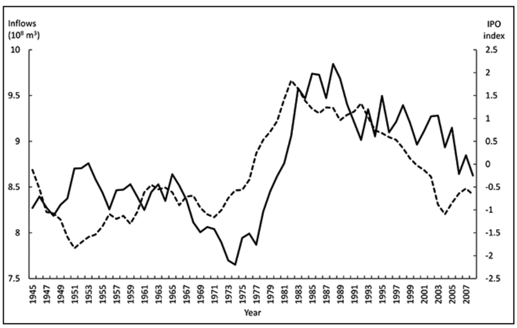

Figure 1 – Smoothed annual Interdecadal Pacific Oscillation index values (dashed) and smoothed combined winter inflows for lakes Tekapo and Pukaki (solid line). Both plots are 11-year running means.

Seasonal lake inflows and the IPO

Figure 1 shows an approximate similarity in the time variation of the annual smoothed IPO index and Waitaki lake inflows in winter, which is not apparent in the other seasons (Fig. 2). There is always a degree of uncertainty in subjective comparisons of temporal variations derived from heavy smoothing, but the post-1978 increase in winter inflows is consistent with the general increase in discharges in the Southern Alps reported by McKerchar and Henderson (2003).

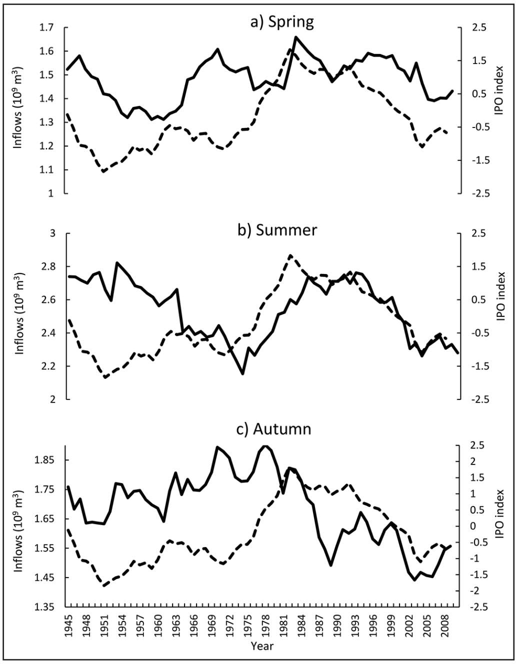

Figure 2 – Smoothed time series, as in the winter plot of Figure 1, for the other three seasons: a, b, and c are spring, summer, and autumn, respectively. The smoothed IPO values (dashed) are replotted for each season.

Proposed climatic mechanism

Taking the winter correlation of Figure 1 as real, it remains to establish a causal mechanism that also explains the lack of association in the other seasons.

It is suggested that the different seasonal correlations of lake inflows to the IPO derive via the intermediary of different seasonal temperature responses to changes in the phase of the IPO. Taking the Hermitage station meteorological site as broadly representative of local temperature variations, smoothed winter temperatures follow roughly similar smoothed trends to the IPO over the period considered (Fig. 3). However, this correspondence of pattern is not evident in the other seasons (Fig. 4). Similarly, there is apparent temporal correlation between winter temperatures and winter lake inflows (Fig. 5), but the correlation is not apparent in the other seasons (Fig. 6).

In seeking a seasonally-variable link between temperature and precipitation leading to inflows, it is interesting to note a correlation between rain-day air temperature and precipitation at the Hermitage station. Taken over all seasons, below 10°C there is a strong association between Hermitage rain-day air temperatures and mean daily precipitation amounts (Fig. 7). This association weakens at higher temperatures, when there is, in fact, some degree of negative correlation.

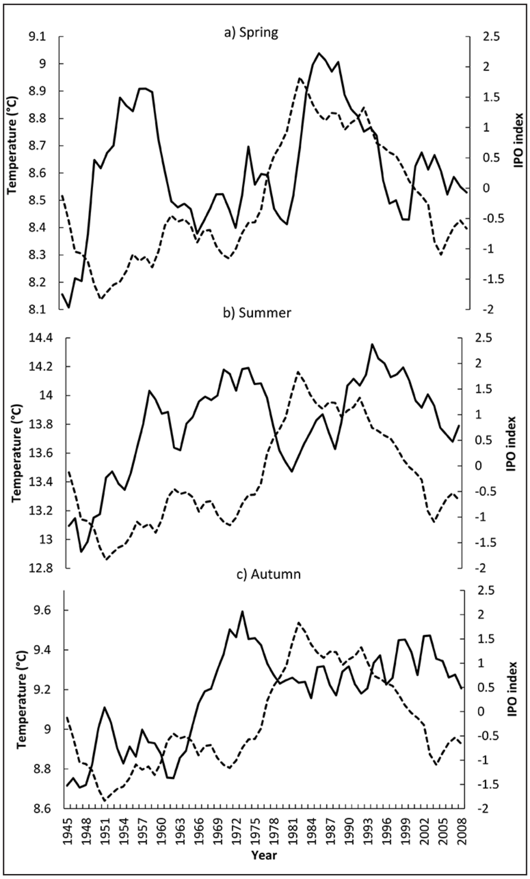

Figure 4 – Smoothed annual Interdecadal Pacific Oscillation index values (dashed line - repeated) and smoothed mean seasonal temperatures at Hermitage station (solid lines).

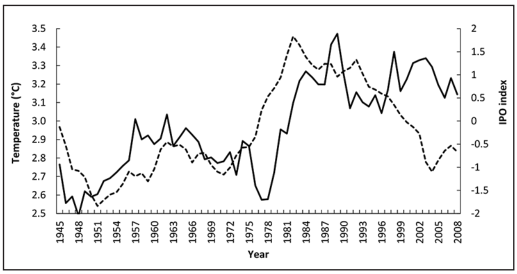

Figure 3 – Smoothed annual Interdecadal Pacific Oscillation index values (dashed) and smoothed winter averaged temperature at Hermitage station (11-year running means).

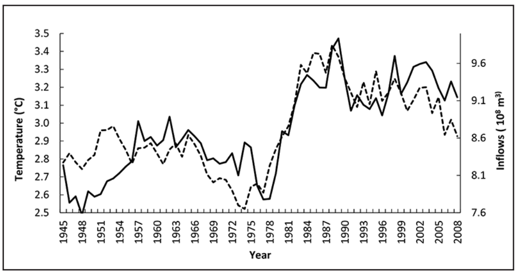

Figure 5 – Smoothed winter mean temperatures at Hermitage station (solid line) and smoothed winter lake inflows for lakes Tekapo and Pukaki combined (dashed line).

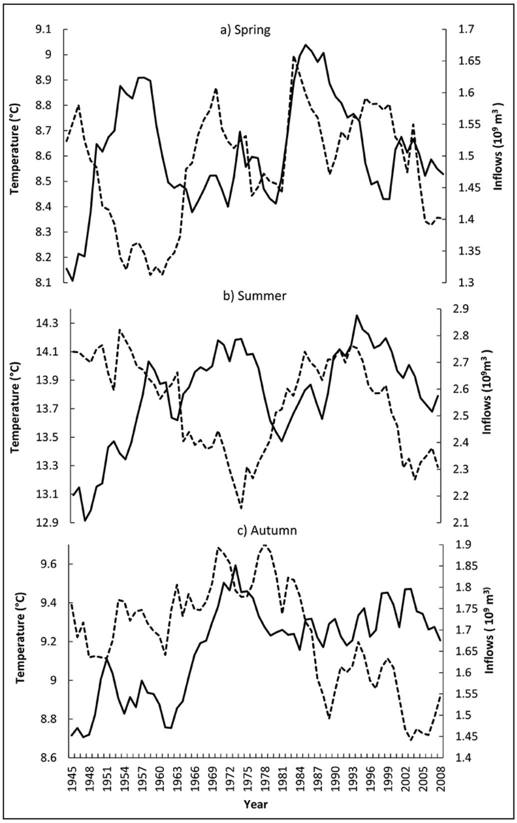

Figure 6 – Smoothed seasonal mean temperatures at Hermitage station (solid line) and smoothed combined lake inflows, for spring, summer and autumn.

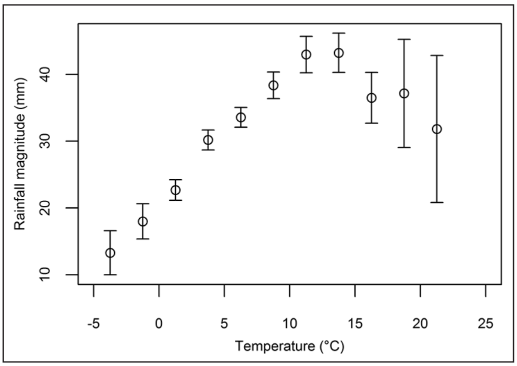

Figure 7 – Mean daily rainfall vs rain-day temperature at Hermitage station (all seasons). Time period is 1940-2008. Bars denote 95% confidence intervals for the means. The means are all calculated for 2.5°C temperature bins.

Seasonal analysis shows the positive temperature association is particularly well reflected in winter because of the weighting toward greater frequencies of colder rain-day temperatures (Fig. 8a). A winter rain-day temperature increase of 1°C equates to an increase in mean precipitation amount of about 2 mm. However, there appears no association between winter mean rain-day temperature and rain-day frequency (Fig. 9). The typically higher rain-day temperatures in the other seasons are in the temperature regions of weaker precipitation-temperature associations of Fig. 7, so the limited degree of association between temperature and precipitation in the other seasons is to be expected (Figs. 8b, 8c, 8d). Consequently, outside of winter there is minimal association between temperature and Waitaki lake inflows, and hence between the IPO and Waitaki lake inflows.

The question of the actual mechanism linking winter temperature and rain-day precipitation is left open. One possibility is a greater frequency of moist winds from the north-west, which may be the mechanism by which the IPO has an influence on temperature. In this regard, Salinger *et al.* (2001) noted changes in wind patterns associated with the IPO. Kingston *et al.* (2014) also described associations between north-westerly wind flow and Waitaki inflows. However, that investigation did not find associations between inflows and larger climatic modes.

The other open question is whether the apparent correlation between IPO and winter temperatures actually translates to sufficient temperature variation to give a causal linkage between temperature and winter runoff in the headwater region (Fig. 5). One issue here is that there will be within-winter seasonal temperature variation and corresponding within-winter seasonal discharge variation, which will together tend to mask IPO-induced temperature linkages to discharge. Separating these components requires

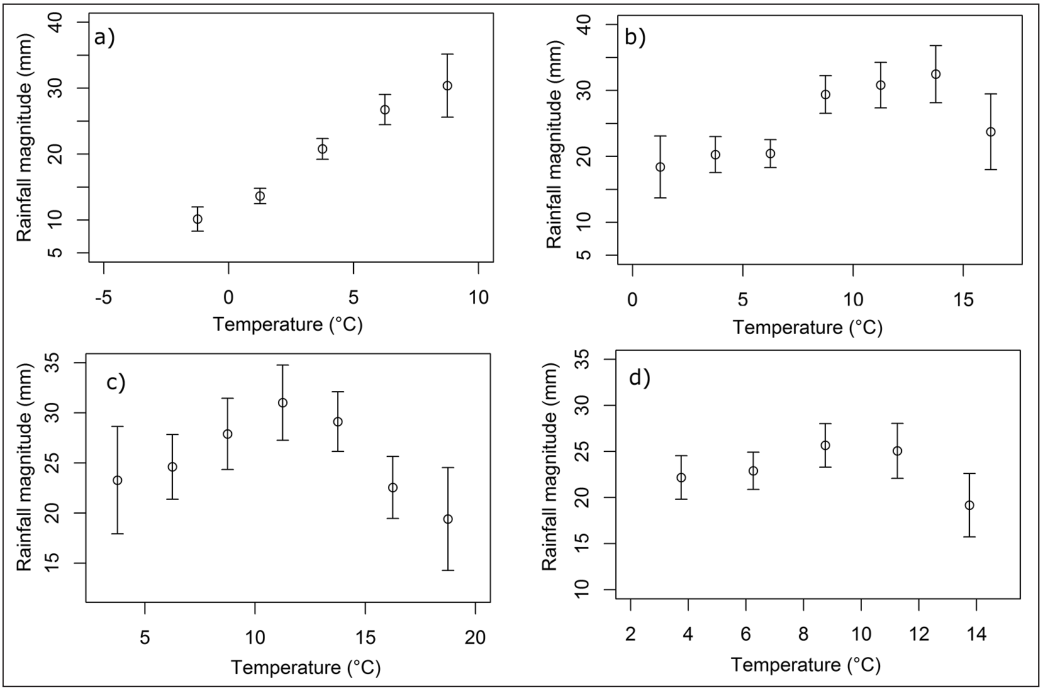

Figure 8 – Mean seasonal daily rainfall magnitude vs rain-day temperature at Hermitage station: a) winter; b) autumn; c) summer; d) spring. The greater width of error bars compared to Figure 7 is a reflection of the smaller amounts of data.

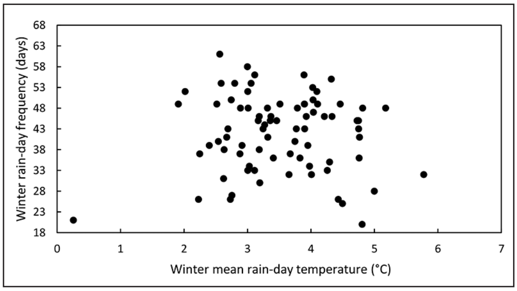

Figure 9 – Winter rain-day frequencies exhibiting minimal correlation with winter rain-day temperatures (Mt Cook, 1940-2008).

further work, so the temperature-related IPO link to winter discharge remains a working hypothesis for now.

The mechanism by which increased winter rain-day magnitudes and temperatures translate to increased winter inflows must involve some degree of interaction with the winter snow pack. Greater precipitation amounts at higher winter temperatures would imply an increased area of the lower elevations receiving precipitation as rain, possibly melting existing snow to add to the increased discharge arising from the greater rainfall magnitudes.

Discussion

There is a climate change implication from the present regional study. Other things being equal, an increase in winter air temperature arising from climate change is likely to result in increased winter precipitation in the Waitaki headwaters. However, for the other seasons there may even be a possibility of decreased precipitation with a temperature increase and thus decreased river discharge.

Further work is needed to investigate in more detail the suggested link, or lack of link, between the IPO and lake inflows for the various seasons. There is also a possibility of repeating this study in nearby regions that may have different hydroclimatic responses.

For example, Taylor and Bardsley (this issue) found spring IPO values of some use in summer headwater flow forecasting for the Clutha River system. On the other hand, forecasting winter inflows appears most promising for the upper Waitaki because winter temperatures and runoff amounts seem to be more influenced by Pacific atmospheric circulation patterns.

Further work might also be directed toward expanding the somewhat arbitrary 'winter' period of June, July and August. Colder conditions might also have a rainfall association in late autumn and early spring, which might be usefully aggregated as part of an expanded 'winter' for the purposes of this type of study. There is also a need to seek longer data periods to confirm the conclusions here, as our data incorporated just a single major change of IPO phase.

Finally, we cannot completely rule out the possibility of imperfect precipitation data playing a role in the results. A reviewer raised the possibility of some hours' delay of snow melt in a gauge (until warmer temperatures allowed melting) and 'precipitation' only then recorded.

Conclusion

It is suggested, for now as a working hypothesis only, that winter Waitaki headwater discharges have a causal linkage to the IPO via the IPO influencing winter rain-day temperatures. This is by way of a strong correlation between winter air temperatures and mean daily precipitation amount. The typically higher temperatures in the other seasons are in the temperature regions of weaker precipitation-temperature association, which in turn contribute to limited inflow correlation. Consequently, the IPO association to Waitaki headwater discharge is confined to the winter season.

Acknowledgements

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